

Allometric Growth in the Striped Marlin, *Makaira mitsukurii*, from New Zealand¹

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INTRODUCTION

MEASUREMENTS MADE on 49 striped marlin obtained by the Yale-New Zealand Expedition, 1948, are the basis for this study. The fish were caught on rod and line between January 31 and March 3, 1948, near Cape Brett, New Zealand. The majority (36) were taken in the immediate vicinity of Cape Brett, at the mouth of the Bay of Islands, while the remaining 13 were caught near the Cavalli Islands, about 20 miles to the northwest. Thirty of the fish were caught by members of the expedition. For the privilege of examining the remaining 19, it is our pleasant duty to extend our thanks to the guests of Otehei Lodge, Otehei Bay, New Zealand. We also wish to thank the proprietors, Mr. and Mrs. G. J. Hassall, and their staff for their generous co-operation and for the excellent working facilities which they furnished us.

The fish measured in this work ranged between 201.9 and 286.5 centimeters in standard length. This is, then, an examination of allometry in adult animals. Ideally, a study of this type would include specimens from the smallest postlarva to the largest adult, thereby providing indices to the growth patterns at all ages and showing when and how these growth patterns change. Because of the methods of capture available to us, however, we were unable to do more than examine fish

of a size commonly taken on rod and line. The world's record for striped marlin is 409 centimeters in total length (about 325 cm. in standard length), and marlin less than about 150 centimeters are rarely if ever taken on rod and line. Since our specimens range from 201.9 to 286.5 centimeters in standard length, we are thus dealing here neither with the largest nor the smallest, but rather with the middle portion of the adult size range.

Studies of allometric growth are applicable to a number of broad problems. They may help to elucidate the laws governing the growth of animals and establish general principles of wide application. They may provide a clue to the mechanics of racion, speciation, and evolution; changing growth patterns, both ontogenetic and phylogenetic, are indicators that these phenomena are taking place. They may indicate whether or not a widely ranging species is homogeneous or composed of a number of separate populations, information which is often vital to the fisheries biologist or conservationist. It was with particular reference to this last point that the measurements here recorded were made. These measurements should be especially valuable to workers who gather similar data on this species in different parts of the world.

MATERIALS AND METHODS

All big-game fish brought in to Otehei Bay were weighed on the official scale of the Bay of Islands Swordfish and Mako Shark Club by G. J. Hassall, weighmaster. Linear measurements were made by us with a tape

¹Scientific results of the Yale-New Zealand Expedition, 1948.

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graduated to $\frac{1}{4}$ inch and read to the nearest $\frac{1}{8}$ inch. For convenience in calculating, inches were later converted to centimeters and pounds to kilograms. These converted measurements are listed in Table 1. It may be added here that measurements made with a tape are not completely satisfactory. As a result of this experience, we suggest the use of large calipers, which can be laid parallel to the long axis of the body and the arms of which are long enough to encompass the greatest depth of the animal. In this way, accuracy will be greatly enhanced.

Throughout this study, use has been made of the logarithmic growth equation, $Y = bX^k$, or $\log Y = \log b + k \log X$, where Y = length of body part, X = standard length, b = initial growth index, k = equilibrium constant (Huxley, 1932: 4-8; Huxley and Teissier, 1936: 780). In the use of this equation, $k=1$ indicates isometry, with the portion under consideration increasing in size at the same rate as the standard length. Similarly, k greater or less than 1 indicates positive or negative allometry, with the body parts increasing at a greater or lesser rate than the standard length. Note also that the units of the body parts are not necessarily equal to the units of the standard length, but are related to them through a factor represented by the constant b . Thus, if X changes by 1 meter and Y changes by only 1 centimeter, then $k=1.0$ and $b=0.01$.

With respect to the length-weight relationship, it should be noted that weight is equal to density times volume. Since volume is the resultant of three dimensions, length, breadth and depth, the length-weight relationship is thus a cubic rather than a linear one. Isometry of length and weight, therefore, must be indicated by $k=3$. In the same way as before, k greater or less than 3 indicates that weight is increasing more or less rapidly than the cube of length, and also shows that the three linear components of weight do not vary at the same rate.

Each set of measurements was plotted on a

double logarithmic scale and regression equations were fitted by the method of least squares. The significance of deviations from isometry was tested by methods outlined by Snedecor (1948: 103-168) and Simpson and Roe (1939: 186-284). Comparisons of k values followed the methods of Snedecor (1948: 318-339) and Simpson and Roe (1939: 277-280). The standard length was always measured along the central axis of the body from the tip of the sword to the center of the notch on the caudal peduncle. Other measurements are described in the appropriate sections.

There appears to be but little data in the literature on allometry in the striped marlin. Gregory and Conrad (1939: Table 1) give detailed measurements of 17 specimens (standard lengths from 250.8 to 284.0 cm.) from Cape Brett, N. Z., and nine specimens (standard lengths from 203.0 to 286.0 cm.) from Mayor Island, N. Z. Shapiro (1938: 1-20) has examined growth patterns in the blue marlin (*Makaira nigricans ampla*) of the Atlantic from 195.0 to 304.0 centimeters in standard length. Where appropriate, we have compared the patterns shown by our sample with the data given by these authors.

GROWTH PATTERNS

The Length-Weight Relationship

In the vast majority of fishes which have been examined from this standpoint, the equilibrium constant of weight on length is approximately 3. However, wide variations have been recorded, from as low as 1.4 (Hile, 1936: 243) to over 3.9 (Shapiro, 1938: 5), in various species. Indeed, comparable variations are to be found between different populations of the same species (e.g., the cisco, *Leucichthys artedii*, according to Hile, varies approximately from 1.4 to 3.7. Although sampling errors may often account for a large portion of the deviations in this relationship (Morrow, 1951: 20-22), real differences in the length-weight relationship undoubtedly in-

TABLE 1
MEASUREMENTS OF STRIPED MARLIN EXAMINED AT OTEHEI BAY, BAY OF ISLANDS, N. Z.*

SPECIMEN NUMBER	WEIGHT	STANDARD LENGTH	SWORD LENGTH	EYE	DORSAL FLUKE OF CAUDAL FIN	VENTRAL FLUKE OF CAUDAL FIN	EYE TO PECTORAL	DEPTH	GIRTH	PECTORAL LENGTH
5.....	93.4	252.0	61.6	5.9	61.0	—	33.6	43.2	106.0	53.0
6.....	98.0	255.0	68.9	—	57.8	55.9	29.9	45.7	107.8	—
7.....	89.4	261.0	67.6	6.0	57.8	57.2	31.1	44.2	102.2	52.1
8.....	142.0	281.3	66.4	7.0	62.8	58.4	34.3	51.4	115.5	53.3
9.....	102.5	263.5	71.4	6.0	62.2	58.4	28.6	43.2	107.8	55.6
10.....	41.3	201.9	52.1	4.8	55.0	50.2	22.9	32.1	79.4	—
17.....	78.0	247.8	66.6	6.0	61.6	57.8	29.2	38.7	95.2	52.7
18.....	112.0	261.3	66.6	5.7	68.9	62.6	28.6	40.0	104.4	55.9
21.....	104.3	253.4	65.4	6.3	64.8	57.1	27.6	41.9	107.9	48.3
38.....	120.2	259.0	67.3	6.3	64.8	58.7	29.8	—	—	52.1
43.....	103.0	262.3	67.6	7.0	62.9	59.7	29.2	45.4	113.6	51.7
45.....	93.9	253.8	69.5	6.0	66.0	60.9	27.3	41.9	104.0	55.9
46.....	84.4	241.5	65.4	5.7	60.0	54.3	27.3	42.9	102.8	48.9
48.....	97.1	255.3	63.5	6.3	64.1	59.1	28.6	42.5	107.9	50.1
49.....	69.8	229.3	61.9	5.7	60.9	54.9	25.4	38.1	91.4	54.6
50.....	94.3	237.2	65.1	6.0	60.6	54.3	26.4	44.4	105.4	48.6
52.....	136.1	286.5	74.3	7.0	69.2	66.0	33.0	50.5	118.1	55.2
53.....	122.5	279.0	71.1	6.7	—	64.1	33.7	47.0	—	57.8
54.....	117.0	255.1	62.8	7.0	58.4	57.2	31.7	45.7	—	59.7
55.....	88.0	257.2	69.2	6.3	66.0	63.5	30.2	38.7	—	54.0
56.....	82.6	255.2	68.6	6.0	61.0	56.5	27.9	37.5	97.2	50.2
61.....	—	230.9	60.3	6.3	60.3	54.0	27.9	42.5	102.6	49.5
62.....	131.1	262.9	67.0	6.7	66.0	59.7	33.4	48.2	119.4	57.8
63.....	88.0	256.8	70.8	6.0	64.8	59.1	27.9	41.9	100.3	57.2
65.....	83.5	251.4	69.8	6.3	59.7	50.9	28.6	—	—	49.5
66.....	128.4	270.0	66.6	7.0	—	—	31.1	—	—	61.6
67.....	94.3	268.5	69.2	6.0	64.1	58.4	30.5	43.2	104.1	57.2
69.....	108.0	273.7	72.4	7.0	63.5	59.0	30.2	45.7	106.6	57.5
70.....	93.4	263.0	75.8	6.0	66.0	61.3	29.2	44.1	104.7	60.3
71.....	76.7	240.0	63.2	5.7	62.2	55.2	27.3	40.0	95.2	49.8
72.....	109.3	261.5	70.8	6.0	67.3	64.1	30.5	46.1	112.4	55.8
73.....	123.4	272.4	72.0	6.7	67.0	60.9	30.2	45.7	116.1	54.2
74.....	93.9	256.2	66.6	6.3	65.1	60.0	29.8	43.5	105.3	52.7
75.....	89.4	247.6	64.8	6.0	65.7	58.8	26.7	43.8	104.7	53.3
80.....	104.3	261.0	68.9	5.7	68.9	63.8	29.8	45.7	109.1	61.6
82.....	73.0	243.9	67.9	6.3	64.1	59.7	28.3	39.1	93.9	53.3
83.....	102.1	270.0	69.2	7.3	63.5	58.1	31.1	44.8	107.2	54.6
84.....	97.1	263.1	71.1	6.3	66.6	61.6	30.2	44.4	107.2	57.5
87.....	129.3	275.1	68.9	6.7	69.8	64.8	31.7	48.6	116.1	59.0
99.....	135.2	283.9	71.7	7.0	69.8	60.0	33.3	48.9	115.1	57.8
114.....	139.7	282.0	76.2	6.7	71.1	64.1	31.5	49.5	120.6	60.3
115.....	152.4	266.0	61.9	6.7	70.8	64.8	32.4	49.9	119.3	59.7
116.....	105.7	270.5	68.6	6.7	63.5	57.2	29.5	41.9	104.0	53.3
117.....	102.5	258.8	67.3	6.3	61.9	57.2	27.9	42.5	107.2	51.4
118.....	111.6	249.3	55.6	6.3	64.8	59.1	29.8	45.7	107.8	53.3
120.....	97.5	233.8	41.3	6.7	64.8	61.6	30.4	44.4	108.5	51.4
121.....	98.0	265.5	69.2	6.3	64.1	60.0	29.8	43.2	106.6	55.2
122.....	82.1	266.7	62.2	6.3	62.8	56.5	27.9	42.2	100.3	52.4
123.....	102.5	257.9	63.5	6.0	58.4	55.9	29.6	43.8	106.6	52.7

*Weight in kilograms, other measurements in centimeters.

dicating different growth patterns, either between species or at different times or in different populations of the same species.

The sample of striped marlin considered here has a length-weight equilibrium constant of 3.009. However, the standard error of k , s_k is 0.307, indicating the possibility of rather wide random variations in k which would not be significant. Shapiro (1938: 5) reported the equilibrium constant of weight on length for the Atlantic blue marlin as 3.93 for a sample of 23 specimens. The difference is quite reasonable, for the blue marlin is a much deeper-bodied fish. It is probable that the Pacific black marlin (*Makaira nigricans marlina*) might have an even higher constant. The white marlin (*Makaira albida*) seems to be a very slim fish and ought to have a considerably lower constant in its length-weight equation.

Linear Measurements

Statistics of the logarithmic regressions of the various linear measurements are given in Table 2. Significant departures from isometry were found in only two of these measurements, although two others, pectoral length on standard length and dorsal fluke of the tail on ventral fluke, approach a significant level. It is possible that examination of larger samples might show the allometry of these dimensions to be significant.

The length of the sword, from the tip to the anterior margin of the eye, maintains an isometric relationship to the standard length. The data published by Gregory and Conrad (*loc. cit.*) give values of k of 0.816 for 17 fish from Cape Brett and 0.889 for 9 fish from Mayor Island. Shapiro (1938: 15) gives $k = 0.88$ for the sword of the blue marlin. None of these figures represent a significant departure from isometry. This is somewhat surprising, for it is popularly assumed that the sword tends to become relatively shorter with increased overall length.

The anterior-posterior diameter of the eye shows a very slight degree of negative allo-

TABLE 2
STATISTICS OF THE LOGARITHMIC REGRESSIONS OF LINEAR MEASUREMENTS ON STRIPED MARLIN FROM NEW ZEALAND

LOG INDEPENDENT VARIABLE, X	N	MEAN LOG X	MEAN LOG Y	$S_{(\log x)^{**}}$	$S_{(\log y)^{**}}$	$S_{(\log x \cdot \log y)^{*}}$	$S_{(\log y \cdot \log x)^{**}}$	k^{\dagger}	s_k^{\ddagger}
Standard length.....	49	2.411	1.822	0.036458	0.087978	0.036704	0.041	1.007	0.216
Eye.....	48	2.411	0.799	0.035588	0.053982	0.030529	0.025	0.858	0.130
Dorsal fluke.....	47	2.410	1.805	0.033822	0.029052	0.018744	0.020	0.554	0.111
Ventral fluke.....	47	2.411	1.770	0.035004	0.032039	0.021378	0.021	0.611	0.110
Eye to pectoral.....	49	2.411	1.471	0.036458	0.064622	0.033859	0.027	0.929	0.139
Depth of body.....	46	2.411	1.640	0.034979	0.064699	0.034926	0.026	0.998	0.139
Girth.....	43	2.410	2.025	0.033704	0.049169	0.031298	0.022	0.929	0.121
Pectoral length.....	47	2.413	1.735	0.023977	0.037343	0.016959	0.024	0.707	0.153
Ventral fluke.....	46	1.769	1.805	0.030645	0.028653	0.025845	0.012	0.843	0.071

* $S_{(\log x)^2}$, $S_{(\log y)^2}$, $S_{(\log x \cdot \log y)}$ = sums of squares and products about mean $\log X$ and mean $\log Y$.

** $s_{(\log y \cdot \log x)}$ = standard error of estimate.

† k = regression coefficient of $\log Y$ on $\log X$.

‡ s_k = standard error of regression coefficient.

metry, but again this is not significant. The measurements made by Gregory and Conrad also do not indicate significant allometry in the eye.

It was not possible to measure the distance between the posterior edge of the eye and the pectoral base along the mid-line of the body with reasonable accuracy, so this measurement was made directly between the eye and the anterior margin of the pectoral base. This distance is distinctly isometric. Even though this is a slanted measurement, it is close enough to the mid-line so that, in combination with the isometry of the sword length, it suggests that the relative length of the head also remains constant.

When the length-weight relationship is isometric, as in the present example, the same condition is to be expected in depth and girth, for these two dimensions may be considered as linear components of weight. One of the more obvious differences in body form between the striped marlin and the blue and black marlins is illustrated more simply by the isometry of these measurements than by the length-weight relationship. In the striped marlin, the equilibrium constants for depth and girth are 0.998 and 0.929, respectively. Shapiro (1938: 7) reports $k=1.45$ for depth of body in the blue marlin. We have found no data on the black marlin, but Nichols and LaMonte (1941: 8) describe this species as "Heavier at larger sizes . . .," which certainly suggests positive allometry in depth and girth. Thus, the greater depth of the body in the blue and black marlins is reflected in the higher equilibrium constants.

The length of the longest ray of the pectoral fin shows slight negative allometry, with $k=0.707$, $P=0.065$. This slight negative allometry is not shared by either of the samples examined by Gregory and Conrad.

The two flukes of the caudal fin were measured along their slant lengths from the anterior end of the corresponding peduncular keel to the tip of the longest ray. The tail is distinctly epibatic. The dorsal fluke is always

slightly longer than the ventral, although there is a tendency in these adult animals for the tail to become more nearly symmetrical with greater size. Comparison of the two flukes shows that the dorsal fluke is negatively allometric with respect to the ventral fluke, with $k=0.843$, $s_k=0.071$, $P<0.05$. Thus, the rate of growth of the dorsal fluke relative to the rate of growth of the ventral fluke decreases as the gross size of the flukes increases.

With respect to the standard length, both the dorsal and ventral moieties of the caudal fin exhibit highly significant degrees of negative allometry in this sample. For the dorsal fluke, $k=0.554$, for the ventral fluke, $k=0.611$. Both these values represent departures from isometry which are significant at $P<0.001$. Thus, the rate of growth of the tail relative to the rate of growth of the fish as a whole tends to decrease rapidly with greater size in adult animals.

It is interesting to compare these data on the tail with those derived from the measurements published by Gregory and Conrad (*loc. cit.*). Their group of 17 specimens from Cape Brett shows negative allometry in the lengths of the caudal flukes quite comparable to that reported here for fish from the same area.

By contrast, their sample of nine fish from Mayor Island, some 175 miles to the south-east, exhibits positive allometry in both the dorsal and ventral flukes, although this allometry is of a low order of significance ($P=0.09$ for the dorsal flukes and 0.04 for the ventral flukes). Nevertheless, there appears to be a real difference between the two geographical groups as shown by a comparison of the k values for the nine fish from Mayor Island and those of the 47 fish of the present sample from the vicinity of Cape Brett ($P<0.001$).

This suggests that the fish from Mayor Island and those from Cape Brett may represent separate populations. However, this suggestion is put forward most cautiously, for

the growth patterns of the tail flukes are the only sets of measurements in which significant differences have been found to exist between the two groups.

SUMMARY

Application of the equation $Y=bX^k$ to measurements of 9 different body dimensions in a sample of 49 adult striped marlin from the region of Cape Brett, New Zealand, has shown that, in general, growth in these fish is isometric with the standard length of the body. Slight but not statistically significant negative allometry was found in the length of the longest ray of the pectoral fin. Significant negative allometry was found in the dorsal and ventral flukes of the caudal fin. A significant difference in the growth pattern of the tail was found to exist between the sample reported here and a sample of nine fish of similar size from Mayor Island, New Zealand, examined by Gregory and Conrad. It is suggested that these two samples may represent separate populations.

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